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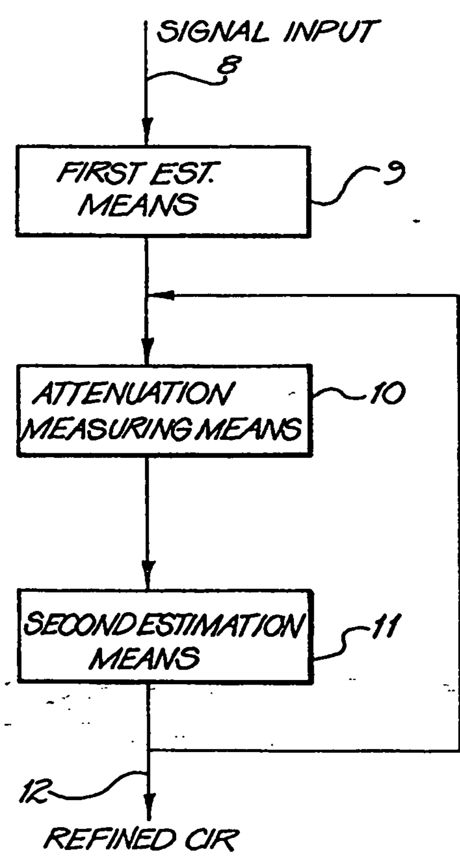
(54) Title: ESTIMATING CIR USING CORRELATION WITH LINE REMOVAL

(57) **Abstract**

The present invention is directed to a method of determining the channel impulse response (CIR) of a communication system, such as the CIR of radio channels of a digital mobile radio network (GSM network). In particular, the present invention relates to determining the CIR based on the reception of a known training sequence. The present invention is based on the realisation that the resolution and dynamic range of the technique based on simple correlation can be improved by using a newly developed "line removal" technique. This involves taking the CIR as determined in the simple correlation, and producing a refined CIR in which the refined CIR is determined by locating the true path delay represented by the peaks resultant from the simple correlation.



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ESTIMATING CIR USING CORRELATION WITH LINE REMOVAL

FIELD OF INVENTION

The present invention is directed to a method of determining the channel impulse response (CIR) of a communication system, such as the CIR of radio channels of a digital mobile radio network (GSM network). In particular, the present invention relates to determining the CIR based on the reception of a known training sequence.

BACKGROUND

In order to determine CIR, a portion of the transmit signal must be known. For a GSM network, Synchronisation bursts (SB) are a useful portion of the signal. The SB are transmitted on at least one channel from every base station, and they are transmitted in a regular pattern. Decoding of the GSM protocols is not necessary. Both the data in the SB and the pattern with which they occur is fixed and substantially identical for all base stations.

The advantage of using SB for determining the CIR is that they represent a relatively long, noise-like predetermined transmitted signal. Typically, 64 bits are transmitted over a period of 237µsec. The determination of the CIR thus requires sufficient synchronisation to the bursts in the received signal to enable the extraction of the SB which is then processed to determine the CIR.

The CIR is determined by using estimation techniques. In order to estimate the CIR, a known training sequence is transmitted $S_{tx}(t)$, and this is corrupted by a communications channel producing the received signal $S_{rx}(t)$. The problem in estimating the CIR is to determine tap-weights $\{\alpha\}$ of a FIR filter (which is used to approximate the CIR), so that the known $S_{tx}(t)$ after passing through the filter is as close as possible to the received signal $S_{rx}(t)$.

Given the that the transmitted Signal $S_{tx}(t)$ and the received signal $S_{rx}(t)$ is known, the CIR can be estimated from:

1. known samples of the transmitted signal $T_k = S_{tx}(t_0 + k\tau)$, $-N_c \leq k < N$ (note that $N + N_c$ samples represent the whole training sequence, the numbering has been arranged to start from the known clean samples of the received signal which occur N_c samples after the start of the training sequence.),

and

2. measured samples of the received signal $R_k = S_{rx}(t_0 + k\tau)$, $0 \leq k < N$ (the first N_c samples of the training sequence are assumed corrupted and are ignored).

The tap weights $\{\alpha_k\}$ are determined by simple correlation as

$$\alpha_k = \sum_{j=0}^{N-1} \bar{T}_{j-k} R_j \quad 0 \leq k \leq N_c \tag{2.1}$$

This algorithm relies on the noise-like properties of the transmitted signal whereby its autocorrection function should have low time sidelobes. The sidelobe performance of this algorithm, however, has been found to be limited due to the correlation properties of the "clean" part of the training sequence and the fact that only partial correlations are performed for later weights.

The results of using the algorithm to determine the CIR of a simple channel is shown in Figure 1. The results indicate a dynamic range of approximately 17dB and a main lobe width of about 9μsec at the -10dB point.

It has been found that the correlation technique is extremely robust in noise, however as can be seen from the illustration of Figure 1, the resolution is poor (wide main beam) and the dynamic range is limited due to relatively high side lobes.

Summary of the Invention

The present invention seeks to alleviate the problems experienced in determining CIR with prior art techniques.

Therefore, the invention discloses a method of estimating the channel impulse response (CIR) of a communication system, the method including the steps of:

(a) providing a first estimation of the CIR by an impulse response calculation using correlation of signals to determine tap weights for said calculation,

(b) determining the true path delay of a radio channel represented by the significant peaks in said first estimation, and

(c) calculating a refined estimation of the CIR using said significant peaks, such that said peaks represent substantially all the energy represented by said first estimation of CIR.

According to another aspect the present invention provides a method of estimating CIR, the method including the steps of

(a) providing a first estimation of the CIR by calculation using correlation,

(b) identifying a first peak having least attenuation in said first estimation,

(c) determining the true path delay represented by the first peak from said first estimation,

(d) calculating a refined estimation of the CIR, from an initial zero refined estimation, by providing a first refined peak in the refined estimation having a path delay corresponding to the true path delay represented by the first peak,

(e) subtracting from the first estimation components corresponding to said first peak;

(f) repeating steps (b) to (e), adding further peaks to the refined estimation until substantially all the energy in said first estimate has been subtracted.

The invention further discloses a device adapted to estimate the CIR of a digital communication system, the device comprising:

first estimating means for determining a first CIR estimation, including impulse response filter means and correlation means for calculating tap weights for said filter means, and

processing means for determining the true path delay represented by the significant peaks in said first estimation, and calculating a refined estimation of the CIR using said significant peaks, such that said peaks represent substantially all the energy represented by said first estimation of CIR.

The present invention also provides a device adapted to estimate the CIR of a digital communication system, the device comprising:

first estimating means for determining a first CIR estimation based on correlation,

first memory means for storing said first CIR estimation,

second memory means for storing a refined estimation of CIR, and

processing means for identifying a first peak having least attenuation in said first estimation, determining the true path delay represented by the first peak from said first estimation so as to define a refined peak, subtracting the correlation components associated with said first peak from said first estimation,

and adding said refined peak into said second memory means, said processing means being controlled such that successive peaks in said first estimated CIR are identified, so that after successive iterations a refined estimation of CIR is stored in said second memory means.

The device may be implemented in software on a suitable processing device.

The present invention is based on the realisation that the resolution and dynamic range of the technique based on simple correlation can be improved by using a newly developed 'line removal' technique. This involves taking the CIR as determined in the simple correlation, and producing a refined CIR in which the refined CIR is determined by locating the true path delay represented by the peaks resultant from the simple correlation.

This allows for the effects of the less noise-like aspects of the known signal for correlation, that is the larger than desired side lobes, to be minimised or removed from the CIR estimate. The most significant features of the initial correlation are progressively removed from the initial correlation by interpolating their true path delay, adding these peaks to a refined estimation, and subtracting the corresponding correlation components from the initial estimation.

Brief Description of Drawings

Preferred embodiments of the present inventions will now be described with reference to the accompanying drawings, in which:

Figure 1 illustrates the CIR using prior art correlation only;

Figure 2 illustrates a refined CIR using the present invention;

Figure 3 illustrates a CIR including adjacent peaks;

Figure 4 illustrates the line removal technique result corresponding to Figure 3;

Figure 5 is a schematic illustration of the refined estimation process; and

Figure 6 is a graphical illustration of the quadratic approximation technique.

Detailed Description

The correlation process detailed in the background has the advantage of being extremely reliable in noise, however, the resolution is poor (wide main beam) and the time sidelobes are larger than is desirable, which limits the dynamic range.

In order to increase the dynamic range, a technique which has been termed "line removal" was developed. The CIR is computed using correlation as described in the background art section, then using the present invention, a refined CIR is generated. In one aspect, all terms in the refined CIR are initially set to zero, the true position and amplitude of a first peak of the CIR is found , and a peak with this true position and amplitude is added to the refined estimation. The contribution from this peak is subtracted from all CIR bins in the initial estimation. A peak of the remaining CIR is found and the process repeated until most of the energy has been subtracted from the CIR or until the remaining peaks have little or no material effect on the resultant refined CIR. This procedure has been found to provide a CIR with very high resolution.

The true position of the peak is preferably found by analysing the value of the bins near the peak. It will be appreciated that the process of allocating the signal to a set of bins will often create a situation where the true peak does not have the path delay attributed to any given bin, so that the energy is spread in the CIR between two adjacent bins, and hence the largest bin value does not correspond to the path delay of the true peak - the true delay is somewhat to one side or another of the largest bin value. Other suitable ways of locating the peak may be used, such as determining the peaks apex, for example by calculation.

Figure 1 shows a CIR obtained by correlation, the channel consists of a single path located at 7μs, which coincides with a 'bin' of the computer CIR. In this case, the peak with the highest value (least attenuation or the highest peak) can be determined by analysing the bin values from bin 0 to bin 14, for example as follows:

Bin no:	0	1	2	3	4	5	6	7	8	9
Bin Value:	-28	-25	-16	-9	-5	-3	-2	0	-2	-3
Bin no:	10	11	12	13	14					
Bin Value:	-5	-9	-16	-25	-28					

It can be seen that the bin with the largest value is bin 7, and that the values in the bins adjacent bin 7 are relatively of equal value on either side of the peak. This can be taken to suggest that the peak real is located at bin 7, and in the example a path delay of 7μsec can be taken as the delay attributable to peak 1. A path delay of 7μsec equates to a defined bin. Thus, in the refined CIR as illustrated in Figure 2, the refined peak 2 has a path delay that corresponds exactly to the 7μsec CIR bin. In the case illustrated in figure 1, extracting peak 1 from the correlation estimate CIR results in the refined CIR illustrated in Figure 2, which provides an extremely clean estimate of the channel response.

If, on the other hand, the single path of the channel was found to lie between bins 6 and 7, for example, then the CIR obtained by correlation would look the same as Figure 1, however shifted slightly to the left (by a fraction of a bin). If the simple line removal algorithm is applied to this then the refined CIR of Figure 3 results. This shows considerable spurious products due to the fact that no allowance has been made for the path to lie between bins. Figure 3 is thus what results if our simple algorithm is applied to a situation where the path delay lies between bins.

In Figure 3 the peak values do not fall cleanly within the bin values - the peak 3 has the highest value from the correlation CIR, but peaks 4 and 5 are of significance either side of or adjacent to peak 3.

The line removal algorithm can be modified to improve performance, this entails allowing for the 'lines' which are removed for the refined CIR to lie in intermediate locations, not just wholly within a bin.

If we knew that the path lay exactly half-way betweens bins 6 and 7, then it is possible to refine the CIR by placing half the amplitude in bin 6 of the refined

CIR and half in bin 7. If we knew that the path lay at 6.4 then 60% of the amplitude would be placed in bin 6 and 40% in bin 7. In general, if the path lies at 6+x (where x < 1), then (1-x) times the amplitude goes into bin 6 and x times the amplitude into bin 7. If this technique is applied where the single path of the channel was found to lie between bins, then the result is Figure 4, a considerable improvement on Figure 3. Note that the peak in Figure 4 extends over 2 bins, contrast to Figure 2 which falls exactly in one bin.

Now the only problem is to determine the value of x. This is where the quadratic interpolation comes in. Imagine that the bins are not as in the table on page 5 but are, for example, as follows:

Bin No.	4	5	6	7	8	9
Bin Value	-4.5	-2.5	-1.5	0	-2.5	-3.5

Note that the peak is in bin 7, however, bins 6 and 8 have unequal values, indicating that the peak actually lies away from bin 7. Quadratic interpolation can be used here to determine the value of x as described.

The assumption is that the data points, or bin values, captured fall on a parabolic curve. The true peak of the curve is at (x_o, y_o). The curve shown in Figure 6 is defined by the function

$$y = y_o - \alpha (x - x_o)^2$$

Assume that 3 data points are available. The time between the data points - "d" - is known, as this is the width of the bin. The value of α determines the curves shape, and is usually known in this application, or can be determined from the determined value for "a".

The observed peak has values

$$y = a \text{ at } x = x_o - \Delta$$

The neighbouring bins have values

$$y = b \text{ at } x = x_o + d - \Delta$$

$$y = c \text{ at } x = x_o - d - \Delta$$

hence,

$$b = y_o - \alpha (d - \Delta)^2$$

$$c = y_o - \alpha (d + \Delta)^2$$

$$\Rightarrow b - c = 4\ \alpha\, d\, \Delta$$

$$\Rightarrow \Delta = \frac{b - c}{4\ \alpha\, d}$$

The values x_0, y_0 can therefore be derived. This process can be readily implemented, for example, in hardware or in software.

Interpolation using such an approximation determines that the true location of the centre of peak 3 is at approximately 5.04µsec. The height of the peak is kept as the height of the original peak. The resultant refined CIR peak 6 with spread calculated is illustrated in Figure 4.

Importantly, the correlation components corresponding to the calculated peak 6 are subtracted from the initial CIR, so as to remove the energy associated with this peak. This process can then be repeated on the residual CIR, which is this case produces a further peak 7 in figure 4. This process can be repeated until all significant energy is removed from the residual CIR, producing a refined CIR with much better dynamic range. The termination point of the process can be determined in a variety of ways. One alternative which is reasonably simple to implement is to run the process a predetermined number of times, say 40, which experience suggests in the systems of interest will capture the relevant peaks. An alternative is to specify a maximum amount of energy, for example 1 %, which can be left in the initial correlated CIR when the refined peaks are subtracted.

The resulting residual 7 as illustrated in figure 4 is lower indicating that the CIR is a better estimate of the channel response. The line removal algorithm has also been found to perform well in noise.

Figure 5 illustrates in a schematic form an embodiment of a device adapted to implement the present invention. The signal input 8 represents the incoming communication system signal. This signal 8 is feed to a first estimation means 9, the function of which is to calculate the first estimation of the CIR using correlation techniques, but without the aid of the present invention. The output of the first estimation means 9 is provided as input to the attenuation measuring means 10. Means 10 determines the position of the first peak with regard to the bin values (that is the highest peak(s) illustrated in Figure 1.). This position

information is provided to the second estimation means 11 which complies a refined CIR based on the location of peak positions, and as described with reference to Figure 1. Path 13 illustrates the iterative nature of the process as described with reference to Figures 2. In the situation described with reference to Figures 4, the attenuation measuring means 10 determines the true path delay of the peak maps a peak spread to the refined CIR 12.

The resulting CIR's generated using line removal have been found to be very suitable for further processing (determining delay dispersion ratio and C/I) as they contain relatively few bins which are non-zero. This speeds these further processing algorithms.

The claims defining the invention are as follows:

1. A method of estimating the channel impulse response (CIR) of a communication system, the method including the steps of:

(a) providing a first estimation of the CIR by an impulse response calculation using correlation of signals to determine tap weights for said calculation,

(b) determining the true path delay of a radio channel represented by the significant peaks in said first estimation, and

(c) calculating a refined estimation of the CIR using said significant peaks, such that said peaks represent substantially all the energy represented by said first estimation of CIR.

2. A method according to claim 1, wherein steps (b) and (c) comprise the steps of

(1) identifying a first peak having least attenuation in said first estimation,

(2) determining the true path delay represented by the first peak from said first estimation,

(3) calculating a refined estimation of the CIR, from an initial zero refined estimation, by providing a first refined peak in the refined estimation having a path delay corresponding to the true path delay and amplitude represented by the first peak,

(4) subtracting from the first estimation components corresponding to said first peak; and

(5) repeating steps (1) to (4), adding further peaks to the refined estimation until substantially all the energy in said first estimate has been subtracted.

3. A method according to claim 1, whereby said first estimation provides a set of amplitude values within equally time spaced bins, and the true path delay is calculated by reference to the values of the bins surrounding the bin having the greatest amplitude.

4. A device adapted to estimate the CIR of a digital communication system, the device comprising:

first estimating means for determining a first CIR estimation, including impulse response filter means and correlation means for calculating tap weights for said filter means, and

processing means for determining the true path delay represented by the significant peaks in said first estimation, and calculating a refined estimation of the CIR using said significant peaks, such that said peaks represent substantially all the energy represented by said first estimation of CIR.

5. A device according to claim 4, wherein said device further comprises first memory means for storing the first CIR estimation, and second memory means for storing the refined CIR estimation.

6. A device according to claim 5, wherein said processing means further includes means for identifying a first peak having least attenuation in said first estimation, determining the true path delay represented by the first peak from said first estimation so as to define a refined peak, subtracting the correlation components associated with said first peak from said first estimation, and adding said refined peak into said second memory means, said processing means being controlling such that successive peaks in said first estimated CIR are identified, so that after successive iterations a refined estimation of CIR is stored in said second memory means.

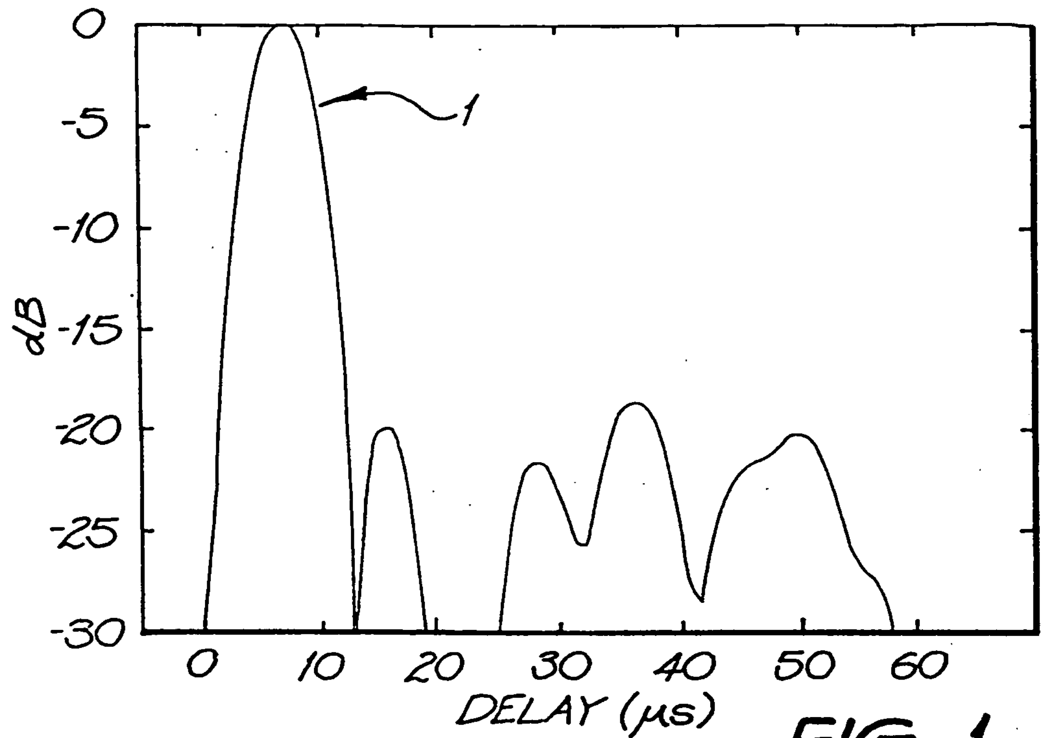


FIG. 1
PRIOR ART

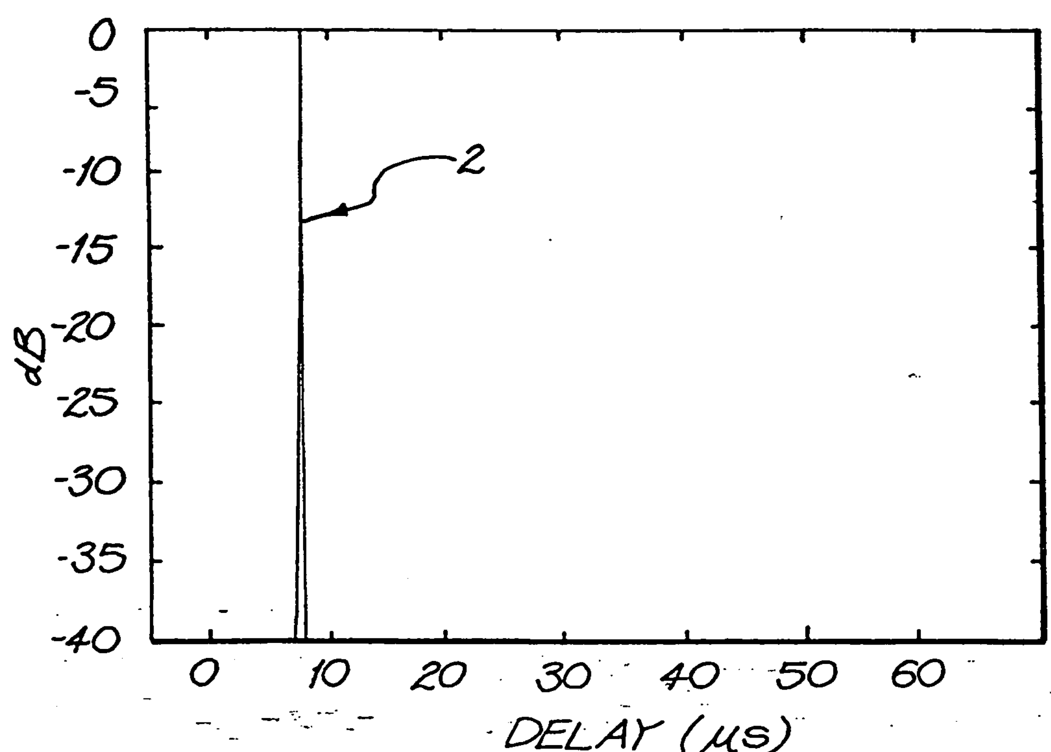
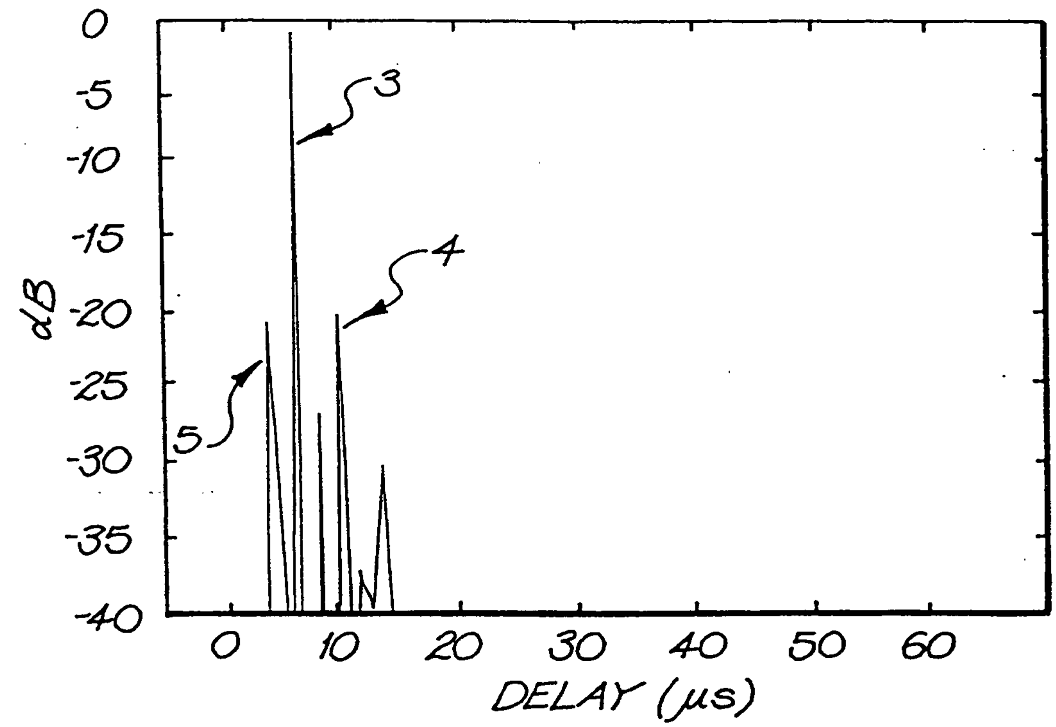


FIG. 2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-5
-10
-15
-20
-25
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dB
3
4
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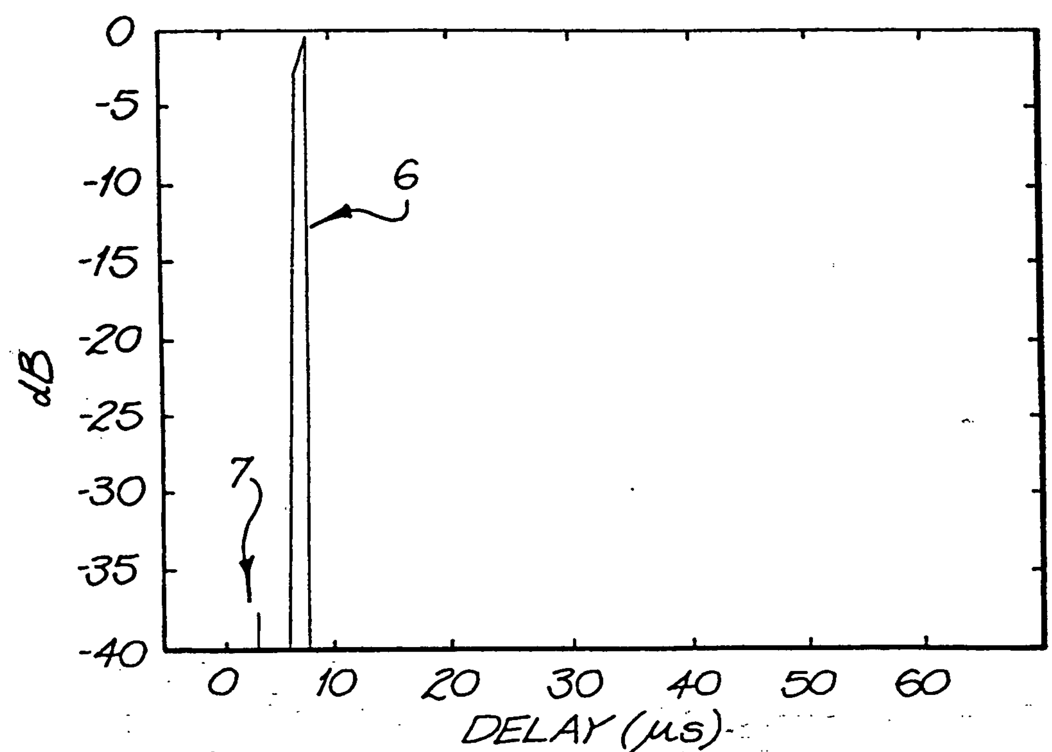
10
20
30
40
50
60
DELAY (µs)

FIG. 3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-10
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-20
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-40
dB
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7
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10
20
30
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60
DELAY (µs)

FIG. 4

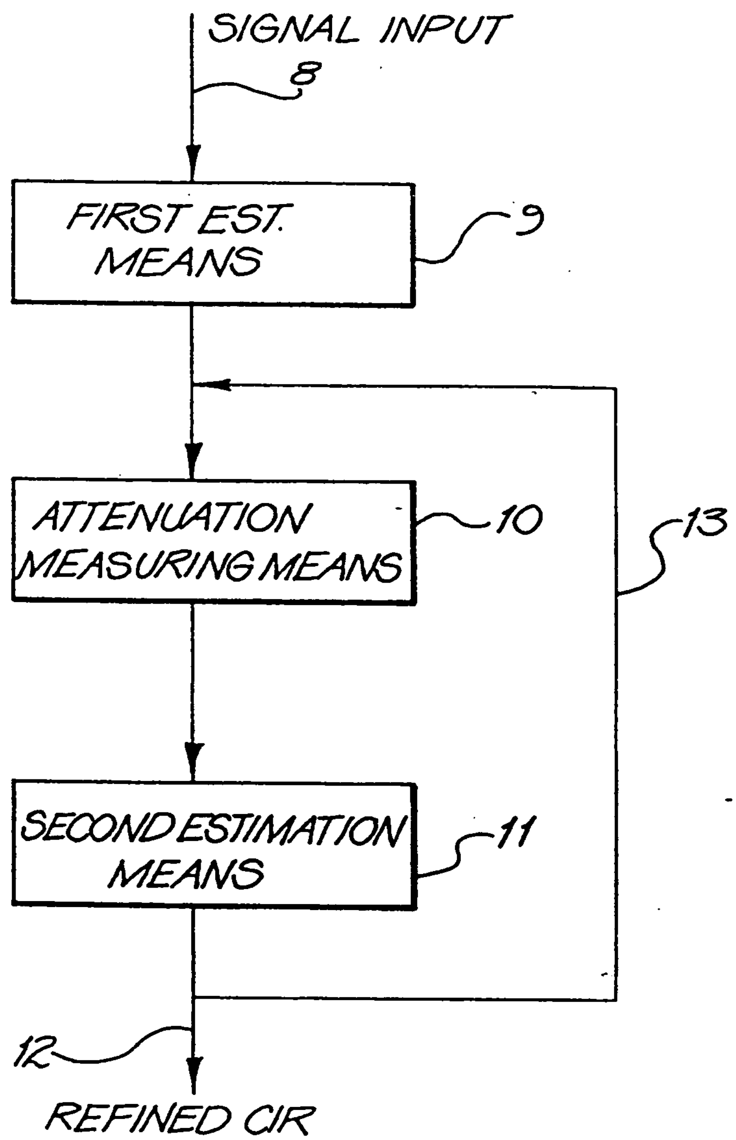
SIGNAL INPUT
8
FIRST EST. MEANS
9
ATTENUATION MEASURING MEANS
10
13
SECOND ESTIMATION MEANS
11
12
REFINED CIR

FIG. 5

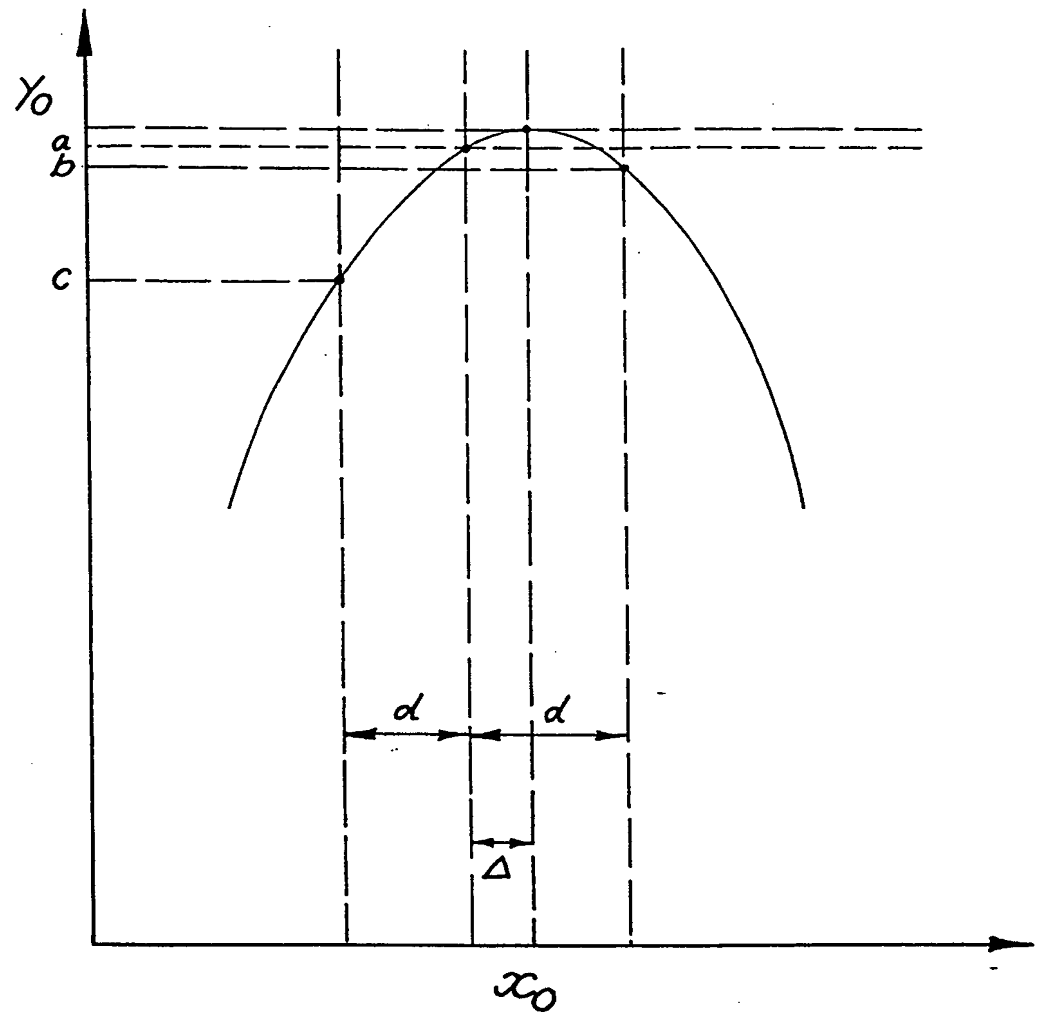

FIG. 6

INTERNATIONAL SEARCH REPORT

Int. tional Application No
PCT/FI 98/00213

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04B7/005 H04L25/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04B H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2 286 509 A (NOKIA MOBILE PHONES LTD) 16 August 1995 see page 1, line 2 - line 5 see page 2, line 5 - page 3, line 2 see page 4, line 1 - line 23 see page 6, line 4 - page 7, line 18 see figures 4-6 ---	1,4
A	WO 96 13910 A (ERICSSON TELEFON AB L M ;SKOELD JOHAN (SE); ERICSSON LINUS (SE); E) 9 May 1996 see page 3, line 14 - page 4, line 16 see page 6, line 34 - page 7, line 18 see page 8, line 14 - page 9, line 12 see claims 1,9; figures 1-4 --- -/--	1,4

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
12 August 1998	20/08/1998

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International Application No
PCT/FI 98/00213

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	WO 94 18752 A (MOTOROLA INC) 18 August 1994 * abstract * see page 3, line 11 - line 23 see page 5, line 34 - page 6, line 37 see page 7, line 35 - page 8, line 25 see claims 1,4; figures 3,4 see figures 4-6 -----	1,4

1

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
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